PB84-148733

Control of Asbestos Fiber Loss from Asbestos-Cement Watermain

Weston Water Utility, Schofield, WI

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Jan 84

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16. ABSTRACT

The Weston, Wisconsin Water Utility discovered the deterioration of a portion of its asbestos-cement watermain and subsequently research to identify an effective means of halting the release of asbestos fibers into its potable water was begun. Three techniques were investigated for eliminating or reducing the release of fibers into the water: (a) formation of a protective metallic precipitate layer on the pipe surface utilizing zinc chloride, (b) in situ cement-mortar lining of the pipe, and (c) flushing of watermains. Implementation of the above three asbestos control processes would have widely differing capital and operational costs.

The introduction of zinc into system water did not result in the expected formation of a protective layer onto pipe coupons, possibly due to interference from polyphosphates added to the system water to sequester iron and manganese. Cement-mortar lining of pipe appears to be a useful technique for rehabilitating pipe which is still structurally sound. However, temporary elevation of values for pH as well as calcium and alkalinity concentrations can be expected. Data from system flushing suggests the concentration of asbestos fibers may become elevated during such high draw conditions. Flushing does not appear to be an effective technique for reducing the concentrations of the fibers.

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CONTROL OF ASBESTOS FIBER LOSS FROM ASBESTOS-CEMENT WATERMAIN

by

Weston Water Utility
Schofield, Wisconsin 54476

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Cooperative Agreement CR-808476010

Project Officer

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DISCLAIMER

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report describes a study undertaken to evaluate three methods for eliminating or reducing the release of asbestos fibers from deteriorating asbestos-cement watermain. The methods evaluated included capital intensive cement-mortar lining, protective metal precipitation using zinc which would require perpetual operational expense, and finally a no cost alternative of watermain flushing.

Francis T. Mayo
Director
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Laboratory

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ABSTRACT

The Weston, Wisconsin Water Utility discovered the deterioration of a portion of its asbestos-cement watermain and subsequently initiated this research project to identify an effective means of halting the release of asbestos fibers into its potable water system. Three techniques were investigated for eliminating or reducing the release of fibers into the water including: (a) the formation of a protective metallic precipitate layer on the pipe surface utilizing zinc chloride, (b) in situ cement-mortar lining of the pipe, and (c) the flushing of watermains. Implementation of the above three asbestos control processes would have widely differing capital and operational costs.

The introduction of zinc into system water did not result in the expected formation of a protective layer onto pipe coupons, possibly due to interference from polyphosphates added to the system water to sequester iron and manganese. Cement-mortar lining of pipe appears to be a viable technique for rehabilitating pipe which is still structurally sound. However, elevated values for pH as well as calcium and alkalinity concentrations can be expected to persist for several months following the relining. Finally, data from system flushing suggests the concentration of asbestos fibers may become elevated during such high draw conditions. This does not appear to be an effective technique for reducing the concentrations of the fibers subsequent to flushing.

This report, prepared by Becher-Hoppe Engineers, Inc., was submitted in fulfillment of Cooperative Agreement CR-808476010 by the Weston Water Utility, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1, 1980 to June 30, 1982, and the work was completed as of April, 1983.

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SECTION 1

INTRODUCTION

DESCRIPTION OF WATER QUALITY

The Town of Weston is located in central Wisconsin (Figure 1) and is a part of the Wausau metropolitan area (see Figure 2). The population of the Township in 1980 was 11,584.

The Weston Water Utility was formed in 1968 to provide potable water and fire protection to the Town of Weston. The utility initially served 69 customers and the original water supply was obtained from the Alta Verde Well (Well No. 1). This well was constructed in 1963 to provide water for a municipal swimming pool, and it was acquired from the Town by the Weston Water Utility at the time of its formation. The Alta Verde well, which produces 400 gpm*, is 79 feet deep with a static water level at 38 feet. This well contains 10 feet of 304 stainless steel screen. The quality of water produced from this well, as determined by the Wisconsin Department of Natural Resources in 1965 and 1966, is outlined in Table 1.

From 1969 through 1971, approximately 90 percent of the water utility's 30 miles of watermain were constructed. Approximately 22 miles of the watermain is made up of asbestos-cement pipe, and all other watermains are either cast or ductile iron.

In May 1972, the Weston Water Utility began to add fluoride to the water supply. Prior to this time no chemical treatment of any type was added to the raw water supply.

In 1972 the Mesker well (Well No. 3) was constructed. (The Weston Water Utility owns and operates Well No. 2 which is separated from the distribution system and serves a single, industrial customer, the Foremost Dairy.) The Mesker well is constructed to a depth of 92 feet in a sand and gravel formation and produces 1,200 gpm. The water quality of this well at the time of its construction (February, 1972), as reported by the Wisconsin Department of Natural Resources is contained in Table 1. There is 20 feet of stainless steel screen in the well and the static water level is at 30 feet. When this well was placed in operation in January, 1974, sodium hydroxide

* English units have been used throughout this report to quantify characteristics which have traditionally been quantified in these units, such as pipe diameters and well construction characteristics. Appendix C presents a conversion table for converting to metric units.

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Figure 1. Location of Weston Water Utility in Wisconsin.

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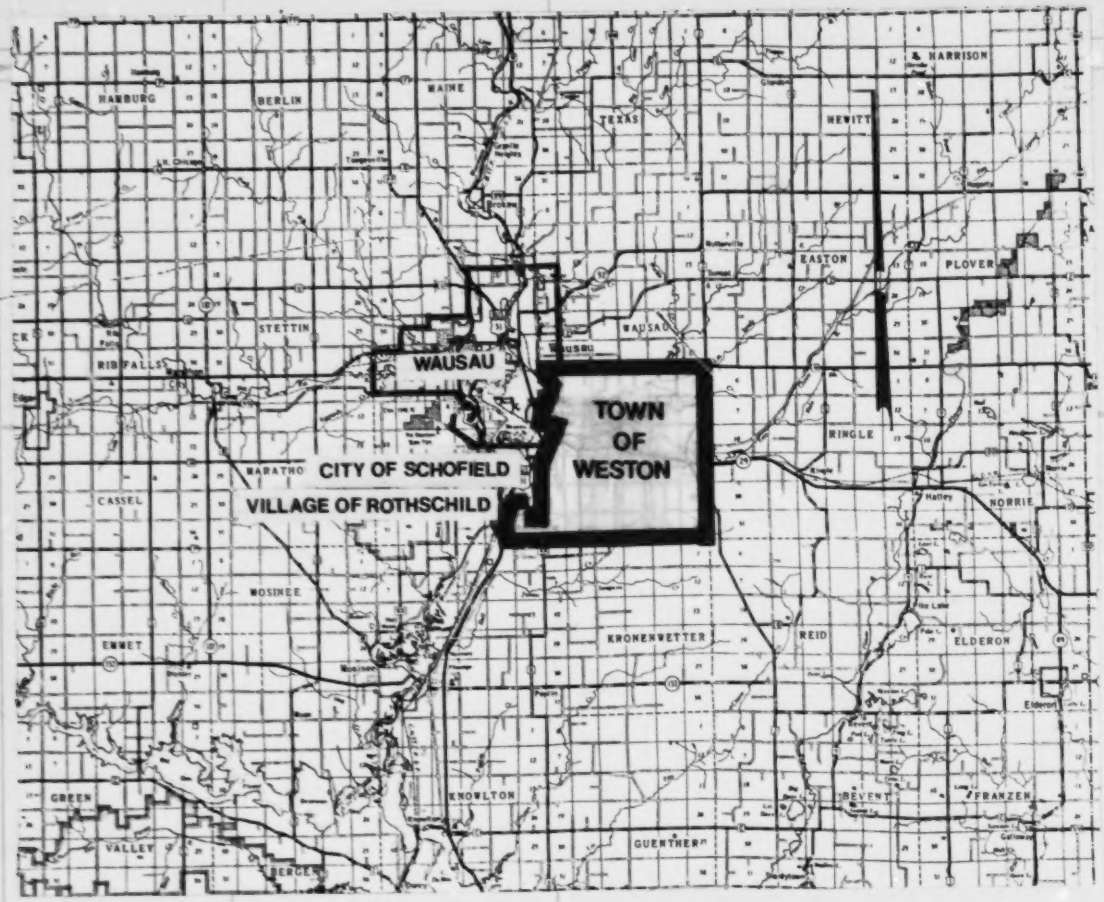

Figure 2. Location of Weston Water Utility in Wausau, Wisconsin Area.

TABLE 1. WATER QUALITY OF UTILITY WELLS AT CONSTRUCTION TIME*+

Parameter	Alta Verde Well 4/8/65	Alta Verde Well 2/4/66	Alta Verde Well 6/28/66	Mesker Well 2/28/72
Total Alkalinity ($CaCO_3$)	58	28	19	16
Calcium	16.4	16	15	7
Chloride	3.5	21	20	6
Fluoride	-	0.1	0.1	0.1
Hardness	76	66	55	28
Iron	0.04	5.6	0.23	.04
Magnesium	-	6.3	4.2	2
Manganese	0.05	0.06	0.04	.04
Nitrate & Nitrite	2.3	1.2	1.8	0.7
Sodium	-	6.5	8.0	3.8
Sulfate	-	21	19	6
Total Solids	100	118	112	56
pH	6.7	6.1	6.0	6.5

* Testing performed by Wisconsin Department of Natural Resources.
\+ All parameters reported in mg/l except for pH.

was added to the water supply for corrosion control. The sodium hydroxide feed was discontinued during the period February, 1975 until August, 1978. Chlorine and a polyphosphate (Aqua Mag) were added to the water supply beginning in December, 1976 to sequester the excess iron present in the well water.

In 1981 the Sternberg well (Well No. 4) was constructed by the Utility. This well, which is 83 feet deep and is constructed in sand and gravel, produces 1,200 gpm. The well includes 20 feet of stainless steel screen and has a static water level at 28 feet. Sodium hydroxide, chlorine and a polyphosphate (WT10) are added to this water for corrosion control and for sequestering iron.

The water distribution system is illustrated in Figure 3. In addition to the wells described above, the Utility also operates two elevated storage reservoirs with capacities of 100,000 and 250,000 gallons.

DISCOVERY OF ASBESTOS-CEMENT PIPE DETERIORATION

In 1980 the Utility was installing a tee in the six inch asbestos-cement watermain on Fox Street to supply a new supermarket with water. Upon removing a piece of this watermain, the Utility crew noted that the interior of this asbestos-cement pipe was very deteriorated and that the original smooth lining of the pipe was no longer present. The crew brought this information to the attention of the Director of Public Works for the Town of Weston. Subsequently, the Utility consulted with the U. S. Environmental Protection Agency (EPA) and this research project resulted.

HEALTH IMPLICATIONS

Though a correlation between the inhalation of asbestos fibers and an increased incidence of lung cancer has been generally accepted by the scientific community, the health hazards associated with asbestos ingestion from drinking water are not well defined at this time. Unlike airborne asbestos fibers, asbestos in drinking water has no set limits for permissible concentrations.

One investigator has found the incidence of gastrointestinal (GI) cancer in asbestos workers to be two to three times the levels found in the general population (1). However, the mechanism for translocating fibers to the GI tract is somewhat uncertain. Inhaled asbestos fibers may subsequently be swallowed. Other studies show that asbestos fibers can penetrate tissue and translocate through the body. A study in Minnesota indicates that asbestos fibers were found in the urine of people drinking water containing the fibers (2).

Three of four epidemiological studies conducted to determine whether ingested asbestos fibers resulted in a potential health hazard found no correlation between asbestos ingestion and the incidence of cancer (3,4 and 5). However, the findings of a fourth study (6) conducted in the San Francisco Bay area did suggest a link between asbestos ingestion and cancer. More study will be required before any definitive answer can be given on this question.

STUDY OBJECTIVES

This study was performed in an attempt to analyze three separate procedures for eliminating or minimizing the number of asbestos fibers being released from the watermains into the water system. The first method was the introduction of a protective zinc coating on the pipe wall by the addition of zinc chloride solution into the water supply. This procedure for controlling the release of asbestos fibers from the pipe would have a low initial capital outlay, but it would require perpetual annual operating costs associated with the necessary chemicals.

A second potential solution to the asbestos fiber problem is that of cement-mortar lining of the deteriorated pipe. Although this method would require a large capital cost, no additional operating and maintenance costs would be incurred.

Finally, watermain flushing was considered as a no-cost method of potential fiber reduction, since flushing is normally carried out as a regular operation and maintenance activity.

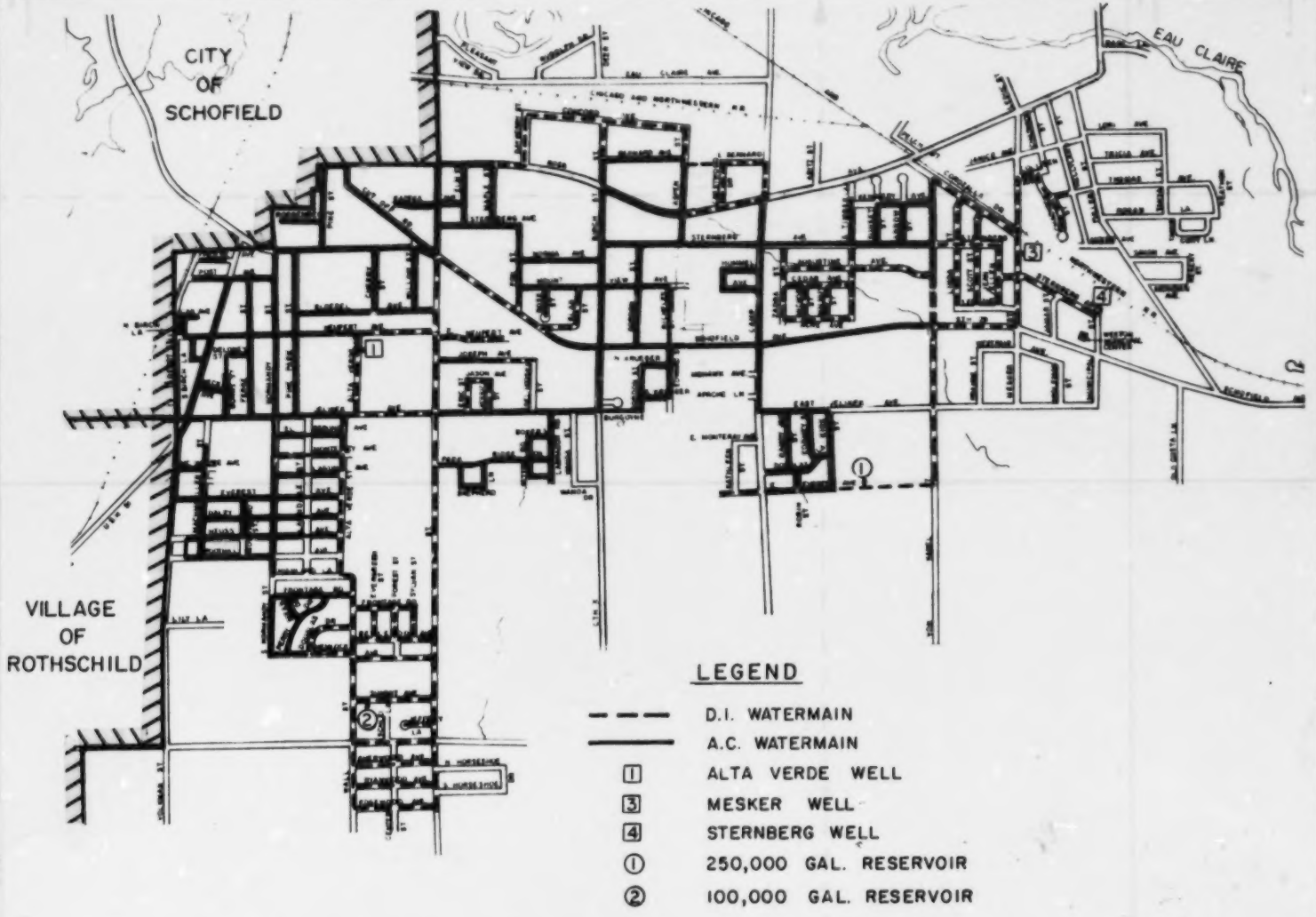

Figure 3. Weston Water Utility Water Distribution System.

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SECTION 2

CONCLUSIONS

1. Although quality control was found to be lacking, the designed water quality conditions in test lines E and F were approximately met. That is, the zinc dosage in line F was higher than that in line E and zinc concentrations were at least of the same order of magnitude as specified in the test design.

2. Coupon weight gain is an inappropriate parameter for estimating zinc precipitation on asbestos-cement pipe. Although this parameter may be acceptable for metallic or plastic pipe materials, the fact that asbestos-cement pipe is porous and subject to considerably greater chemical and physical reactions with water makes an alternative method for determining zinc precipitation necessary.

3. Based on the lack of positive results for both sample thickness measurement and hardness testing, it appears that zinc did not precipitate onto the pipe sample coupons to form a protective metallic layer. Since positive results for this procedure have been reported elsewhere, it is believed interferring factors, possibly the presence of polyphosphates added to the utility's water, may be responsible for the lack of success.

4. All 15 deteriorated pipe samples were found to have measured wall thicknesses in excess of the manufacturer's minimum standard. However, it is likely that the softened portion of the pipe wall contributes less strength than that portion showing no calcium loss. All 15 of the above samples had undeteriorated wall thicknesses which are less than the manufacturer's standard. Therefore, the structural stability of the pipe is unknown.

5. Based upon the results of calcium loss distances and calcium to silicon ratios conducted on pipe samples following successive cleaning runs, it appears neither cleaning method utilized was completely successful in removing the entire softened zone of the pipe.

6. No apparent relationship could be discovered between the microscopic observations and the deteriorated zone of the pipe coupon.

7. Results of the water quality analyses of samples taken during the recirculation tests, conducted prior to cement-mortar lining, indicated that the system water is corrosive in nature.

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8. Water quality parameters including pH, alkalinity and calcium concentrations were considerably elevated upon completion of recirculation test runs conducted after the cement-mortar lining. It is concluded that these elevated values resulted from the curing of the cement-mortar material, since these parameters showed a definite decreasing trend with successive recirculation test runs.

9. The tank truck used to provide water for the recirculation test was found to be contaminated with amphibole asbestos fibers. The fiber concentrations found in the tank truck were near the limits of detectability. This was similar to the concentrations which were found in the watermain recirculation samples. Therefore, nothing can be concluded relative to whether or not amphibole asbestos fibers are being released by the pipe wall.

10. The lack of any high values (greater than 10 million fibers per liter, [MFL]) of chrysotile asbestos fibers found subsequent to the cement-mortar lining indicates that this process may be effective in preventing the release of these fibers from the deteriorating pipe.

11. The results of the flushing test indicate that chrysotile asbestos fibers may tend to increase in concentration following a high draw flow situation. However, because of the limited data supporting this conclusion, it is recommended that it be verified by collecting more data. On the other hand, the amphibole fiber concentrations do not appear to be similarly affected by a high draw situation.

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SECTION 3

RECOMMENDATIONS

1. Lack of test control exhibited by this project leads to the recommendation that a detailed test procedure be established prior to work being carried out. Such a test procedure for this project might include flow recording, zinc concentration and pH sampling.

2. It was concluded that sample weight was an inappropriate parameter for measuring zinc precipitation on asbestos-cement pipe. It is recommended that an alternative procedure for measuring zinc be established. This might be accomplished by pulverizing and dissolving a portion of the pipe coupon, and chemically analyzing for zinc. Alternately, it may be possible to analyze for zinc using x-ray technology.

3. Zinc precipitation onto the pipe coupon is a surface area related process. Therefore, all pipe coupons should have as similar dimensions as possible. Grinding of test coupons to exact dimensions is recommended to insure maximum uniformity.

4. Establishing coupon "dry" weight may be necessary for future work involving asbestos-cement pipe research. Noting the difficulty of obtaining reproducable dry weights with this porous material, it is recommended that an arbitrary "dry weight" standard be established. Noting further that coupon weights were within 1% of the 97 day dry weight after the initial five day drying period, it is recommended that a five day drying period, following procedures specified in Section 5 of this report, be utilized as such a standard.

5. The apparent lack of success with precipitating a protective metallic zinc layer on the asbestos-cement pipe material may be due to the zinc being sequestered by polyphosphates added to the water to sequester divalent iron and manganese. Further research is recommended to investigate the relationship between zinc and polyphosphates.

6. Since it was concluded that neither method of pipe cleaning was entirely successful in removing the entire deteriorated zone of the watermain, further investigations should be made relative to the degree of pipe cleaning found to be necessary to obtain a satisfactory cement-mortar lining. If structural integrity of the lining is provided by the continuous ring established by the lining itself, as suggested in the literature contained in Appendix A, and not the bonding between the lining and the pipe wall, the need for any cleaning at all may be delegated to concerns of secondary importance.

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7. The hardness analysis indicates that deteriorated pipe becomes soft. It is recommended that it be confirmed that this softness exists only in the deteriorated zone of the pipe, and does not extend into the pipe layers not exhibiting calcium loss. This could be done by successively grinding off surface layers of the pipe and retesting for hardness. If confirmed, this method may be utilized as an alternative to the more technically complex methods of determining the thickness of the deteriorated pipe layers which require the use on electron microscopy.

8. It is recommended that samples of asbestos-cement pipe from throughout the distribution system be tested for structural strength, if all asbestos-cement pipe is to be considered for cement-mortar relining.

9. Should cement-mortar lining be decided upon as a remedial solution for halting the release of asbestos fibers into the water distribution system, consideration should be given to the temporary effects high pH conditions might have on other ionic species present in the water, particularly metals for which primary drinking water standards have been established.

10. Because of the complexities involved in identifying and quantifying asbestos fiber concentrations, it is recommended that results be presented in terms of ranges based on statistical confidence intervals, rather than discrete values. In order to accomplish this a statistical analysis will need to be performed for each asbestos fiber standard. The statistical analysis should conform to that recommended in the Interim Method for Asbestos in Water (8).

11. Although it appears that flushing watermains may increase the concentrations of chrysotile concentrations, this finding should be verified by further research, due to the lack of statistically significant data values obtained from this study.

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SECTION 4

EQUIPMENT, TEST DESIGN AND OPERATION

ZINC PRECIPITATION TREATMENT

This test was designed to evaluate the effectiveness of a precipitated zinc pipe coating in preventing the release of asbestos fibers from both new and deteriorated asbestos-cement pipe. This test subjected sample pipe coupons to the utility's water supply treated with 1 mg/l $ZnCl_2$ without any adustment of the pH of the water, and 2 mg/l ZnCl with pH adjustment to 8.5. Pipe sample coupons which were subject to existing utility water conditions were also included in this test as a control.

In order to carry out this test, a pipe header was constructed within a lift station located adjacent to Fox Street. A schematic diagram of the test header is contained in Figure 4. All piping used for the construction of the test header was schedule 40 PVC pipe, with teflon tape used on the threaded connections. Three individual lines were constructed, each containing a ball valve and pressure gage for flow control and a 3/4 inch water meter with totalizer and rate of flow indicator. The flow rate past the pipe coupons was initially set at the beginning of the test to be 4 gpm. However, no subsequent rate of flow data were recorded. Only the total flow over the 217 day test period was recorded, which indicated that the actual flows averaged from 3.73 to 3.84 gpm within the three lines over the duration of the test.

A PVC coupon holder, constructed of 2½ inch diameter pipe six inches long, was located downstream from each water meter. Each coupon holder was capable of containing two 3 inch by 1-3/4 inch pipe coupons held end to end. This would insure that equal volumes of water pass over both coupons. The holder also included a union coupling to permit easy removal of the coupons. A water sample tap was located on the discharge side of the coupon holder. However, only one such sample was taken during the test. In test lines E and F a chemical solution application nipple was installed mid-way between the watermeter and the coupon holder to insure adequate mixing of the chemicals prior to contact with the coupons. All water utilized in the three test lines was obtained directly from the distribution system which in turn was supplied solely from the Mesker well. (The Alte Verde well was not run during this period, and the Sternberg Well had not yet been constructed.)

Pipe coupons were prepared from both new and deteriorated asbestos-cement pipe. The deteriorated pipe was removed from the Fox Street main.

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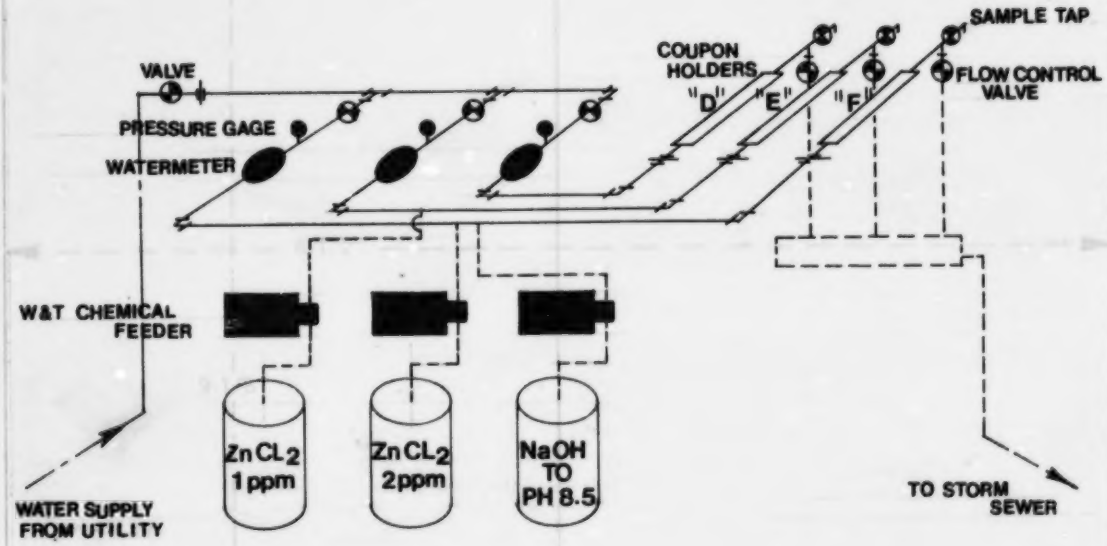

Figure 4. Schematic of Test Header for Zinc Precipitation Test.

The pipe coupons were weighed, without any special drying considerations, and were then placed in the coupon holders. The coupon test header then received a continuous flow of water from December 2, 1980 until July 7, 1981. Lines D, E and F received total flows over this period of 1,198,790 gallons, 1,166,750 gallons and 1,167,680 gallons respectively.

The coupons were subsequently removed and weighed. Again no particular attention was given to the moisture content of these coupons. After it was realized that the moisture content of the coupons may significantly affect the conclusions derived from this test, the coupons were shipped to the EPA research laboratory in Cincinnati for drying and weighing. The relative hardness of each of the pipe samples was also determined by EPA.

CEMENT-MORTAR LINING

The length of asbestos-cement watermain on which the deterioration was initially discovered was subdivided into three test sections labeled A, B, C respectively. A schematic drawing of the test sections is given in Figure 5.

Test Section "A" consisted of a 308 foot length of 6 inch asbestos-cement watermain between State Highway 29 and Mount View Avenue. Section "B" consisted of 439 feet of pipe between Mount View and Norma Avenues. Section "C" included 427 feet between Norman and Sternberg Avenues. Two inch schedule 40 PVC pipe was constructed parallel to lines "A" and "C" in order to allow recirculation of water through these two mains. Sampling points were established at the 1/3 and 2/3 points along the length of each watermain test section. On test line "A" sampling access to the asbestos-cement pipe was accomplished by excavation and filling with a backhoe. On test line "C" permanent wood crib structures were constructed to permit ready access for sampling the pipe. The test procedures performed on each line were as follows:

Test Procedures for Section "A"

(A) Pipe samples were obtained prior to any testing.

(B) On November 12, 1980 the line was cleaned with a single pass of a rubber disk scraper. Cleaning was performed under the direction of personnel from Raymond International, Inc.

(C) Pipe samples were taken.

(D) On November 13, 1980 the line was scraped using a cable-pulled metal scraper. This procedure was also performed under the direction of personnel from Raymond International, Inc.

(E) Pipe samples were taken.

(F) The line was flushed with water taken from the Mesker Street pump house hydrant and delivered to the site by tank truck. The flushing

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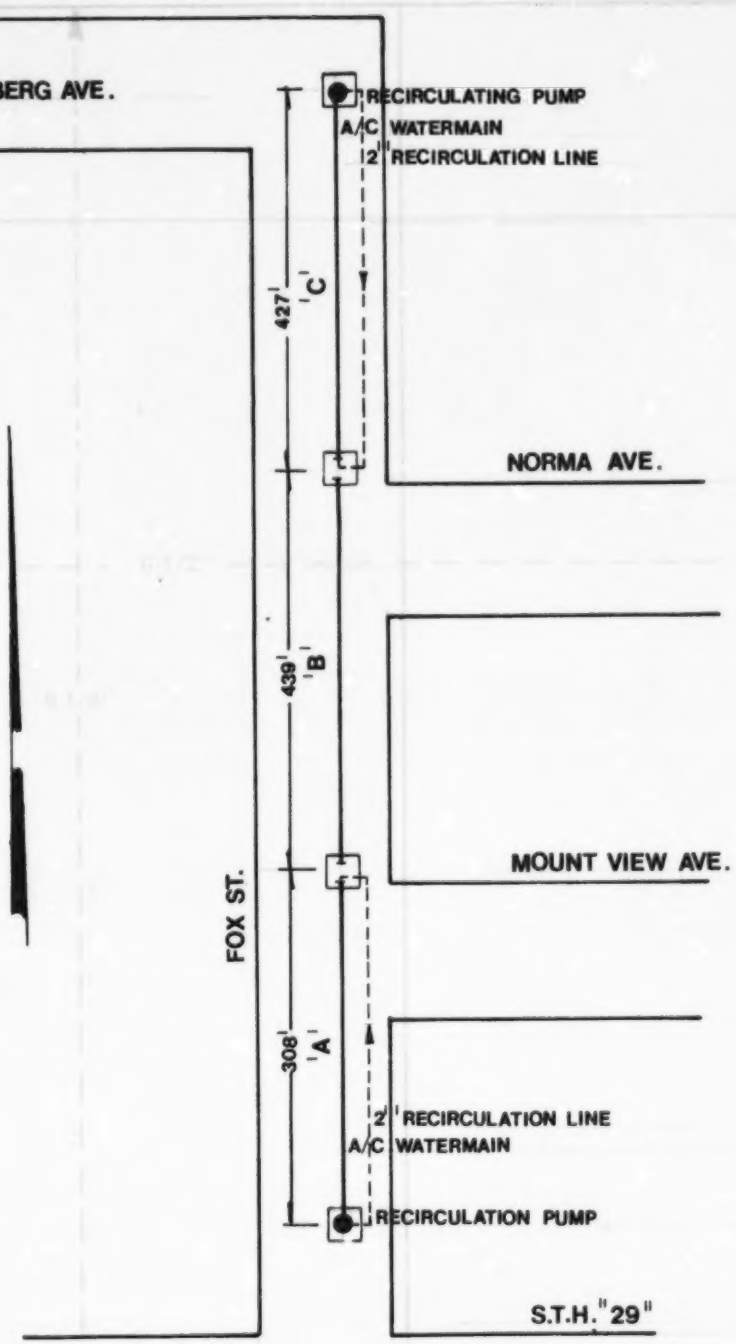

Figure 5. Schematic Diagram of Fox Street Watermain Test Sections "A", "B", and "C".

was accomplished by allowing the entire capacity of the tank truck, approximately 700 gallons, to drain through the line by gravity. Afterward the line was drained and plugged.

(G) On November 17, 1980 the line was filled with water from the same source as described in (F) above, and recirculation through the line was begun. A water meter was used to record the amount of recirculation provided.

(H) A water sample was taken from a fire hydrant at the Mesker Street well and analyzed for water quality and asbestos fibers.

(I) On December 2, 1980, a water sample was taken from the line after approximately 60,000 gallons of water had been recirculated. The sample was analyzed for asbestos fibers and water quality.

(J) On December 4, 1980 the line was drained and plugged.

(K) In June, 1981, the line was cement mortar lined by personnel from Raymond International, Inc. For a description of the lining process, refer to Appendix A.

(L) On November 9, 1981 pipe samples were taken (Samples not analyzed).

Test Procedures for Section "B"

(A) Pipe samples were taken prior to any test activities.

(B) On November 12, 1980 the line was cleaned with a single pass of a metal scraper. The line was in a dry or basically dry condition as the pipe had been exposed at both ends for several weeks prior to the scraping. The cleaning was performed under the direction of personnel from Raymond International, Inc.

(C) Pipe samples were taken following the cleaning. Ends of the pipe section were then plugged.

Test Procedures for Section "C"

(A) Pipe samples were taken prior to any subsequent test work.

(B) On November 18, 1980 the line was "pigged" by one pass of a two pound per cubic foot polyurethane foam pig (swab). The pigging was performed under the direction of personnel from Becher-Hoppe Service Corporation.

(C) Pipe samples was taken.

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(D) On November 19, 1980 the line was pigged with two passes of a five pound density red criss-cross pig as manufactured by Girard Polly-Pig, Inc.. The pigging was performed by personnel from Becher-Hoppe Service Corporation.

(E) Following the pigging, the pipe was flushed and filled with water obtained from the hydrant at the Mesker Street well and delivered to the test site by fire truck. The flushing was accomplished by utilizing a tank truck having a capacity of approximately 700 gallons. The entire contents of the completely filled tank was allowed to flush through the line by gravity.

(F) On November 21, 1980, recirculation of the water in the line was begun and continued until November 25, 1980. Approximately 25,500 gallons of water were recirculated, based on information obtained from the recirculation line meter.

(G) On November 25, 1980, recirculation was terminated, and a water sample taken from the line was analyzed for water quality and asbestos fibers.

(H) The line was pigged with two passes of a five pound density silicon carbide coated pig as manufactured by Girard Polly-Pig, Inc. The pigging was performed by personnel from Becher-Hoppe Service Corporation.

(I) A pipe sample was taken.

(J) The line was flushed with water obtained from the Mesker Street well in the manner described in Step (E) above. The line was subsequently refilled with water from this source and recirculation of the water was begun.

(K) On December 2, 1980, a water sample was taken after a volume of 67,300 gallons had been recirculated through the pipe. The sample was analyzed for asbestos fibers and water quality.

(L) The line was pigged with three passes of a five pound density, wire scraper pig as manufactured by Girard Polly-Pig, Inc. The pigging was performed by personnel from Becher-Hoppe Service Corporation.

(M) The line was drained and plugged following the pigging.

(N) Pipe samples were taken.

(O) On December 4, 1980, the line was pigged using one run of a two pound density pig and one run of a five pound density red criss-cross pig as manufactured by Girard Polly-Pig, Inc. The pigging was performed by personnel from Becher-Hoppe Service Corporation.

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(P) Following pigging the line was flushed with water obtained from the Mesker Street well in the manner described in Step (E) above. The line was subsequently drained and the pipe ends were plugged.

(Q) On December 5, 1980 the line was filled with water obtained from the hydrant outside the Mesker Street well, which was delivered to the site by tank truck. Recirculation of the line was begun.

(R) On December 30, 1980, water samples were taken and analyzed for asbestos fibers after 173,700 gallons had been recirculated.

(S) On February 19, 1981 the line was flushed with water obtained from the hydrant at the corner of Fox Street and Norma Avenue. The line was subsequently drained and plugged.

(T) In June, 1981, the line was cement-mortar lined by personnel from Raymond International, Inc. Refer to Appendix A.

(U) On October 6, 1981, the line was flushed with water supplied from the Town's Municipal Center well (private: not connected to the distribution system) in the manner described in Step (E) above. A sample taken from the tank truck was analyzed for water quality parameters.

(V) On October 7, 1981, additional water from the Town's Municipal Center well and delivered by tank truck was introduced into the line to remove ali entrapped air.

(W) On October 9, 1981, recirculation of the water in the line was begun.

(X) On October 12, 1981, a water sample was taken and analyzed for asbestos fibers after an estimated recirculation volume of 50,000 gallons had passed through the pipe loop.

(Y) On October 15, 1981, a water sample was taken and was analyzed for asbestos fibers and water quality.

(Z) The line was drained, flushed in the manner outlined in Step (E), and again refilled with water obtained from the Municipal Center well and delivered by tank truck.

(AA) On October 16, 1981 recirculation of the line was begun.

(BB) On October 26, 1981, water samples were taken from the line and analyzed for asbestos fibers and water quality.

(CC) The line was drained.

(DD) Pipe samples were taken. (Never analyzed).

(EE) The line was flushed with water obtained from the Mesker Street well in the manner described in Step (E). The line was refilled with water from this source.

(FF) Water samples were taken from the hydrant at the Mesker well and analyzed for asbestos fibers and water quality.

(GG) Recirculation was begun.

(HH) On November 9, 1981, a water sample was taken from the line and was analyzed for asbestos fibers and water quality.

(II) Pipe samples were taken. (Never analyzed).

(JJ) The line was drained, refilled with water obtained from the Mesker Street well and plugged.

This completed the tests related to pipe cleaning and lining.

SYSTEM FLUSHING

A flushing test was conducted on Kirk Street on December 8, 1981. The section of watermain on which this flushing test was conducted lies between East Everest and Jelinek Avenues and is illustrated in Figure 6. This section of eight inch asbestos-cement watermain is approximately 1,400 feet in length and was installed in 1970. This portion of the watermain was isolated from the remainder of the system by closing valves as illustrated in Figure 6.

During the test water samples were obtained at two points: a house located at 6102 Kirk Street and another at 6303 Kirk Street. Samples were obtained through the exterior hose bib at both of these dwellings. The water samples were analyzed for asbestos fiber concentrations by Montgomery Laboratories. During the sampling special note was made of the volume of water passing through the meters located in these residences. This was done to insure that adequate volumes of water had passed through the service laterals and interior plumbing to insure that the water being sampled was that which had passed through the watermain in a high velocity condition.

This flushing test was conducted in two distinct segments. Flow Test One consisted of flushing the water in a northerly direction along the Kirk Street watermain and exiting the system at test flow Hydrant One. Water being supplied for Test One was supplied from the nearby well and the 250,000 gallon elevated tower. Flow Test Two consisted of a high velocity flow occurring in the reverse (southerly) direction. The water supply for Test Two was from the distribution system to the West. During each test, a rate of flow and velocity were calculated using measurements of the static and flowing water pressures recorded at the discharge hydrant . The flow during Test One was approximately 1,100 gpm with an approximate velocity of seven feet per second. During Test Two the flow was calculated to be

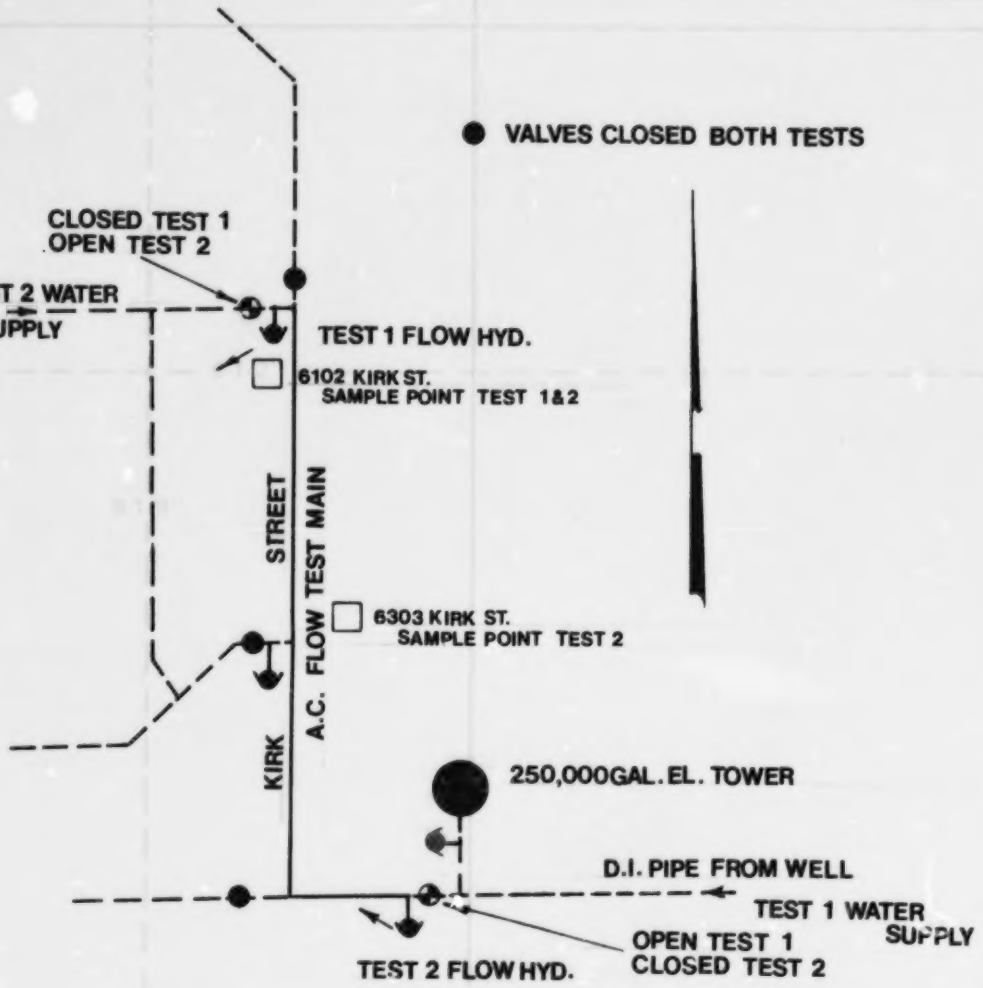

Figure 6. Schematic Diagram of Flushing Test on Kirk Street.

820 gallons per minute with an average velocity of five feet per second. The procedures followed during the flushing test are as follows:

Test No. 1

(A) A background water sample was obtained from the sample location at 6102 Kirk before flushing was started.

(B) Flushing of the pipe was begun by closing the valves as indicated in Figure 6 and opening Test Hydrant One.

(C) After 25 minutes of flushing a sample was taken from 6102 Kirk.

(D) After an additional 85 minutes another sample was taken from 6102 Kirk.

(E) After an additional 90 minutes another sample was taken from 6102 Kirk.

(F) Test Hydrant No. 1 was closed.

Test No. 2

(G) Test Hydrant No. 2 was opened and valves opened and closed as indicated in Figure 6 to meet the conditions of Test No. 2.

(H) After 15 minutes a water sample was taken from 6102 Kirk.

(I) After an additional 25 minutes a water sample was taken from 6303 Kirk.

(J) The test was completed. Both hydrants were closed and all valves were opened.

(K) A water sample was taken from 6102 Kirk six days later (December 14, 1981).

This completed the flushing tests.

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SECTION 5

SAMPLING AND ANALYSIS

ZINC PRECIPITATION TREATMENT

Preparation of Coupons for Zinc Chloride Test

Pipe coupons were prepared for this test by removing approximately a six inch annular section from both the new and existing asbestos-cement pipe specimens. From these sections, smaller coupons having dimensions of 3 inches long by 1-3/4 inch wide were cut.

Coupon Weight Determination as Performed by Zimpro, Inc.

Prior to the initiation of the test, pipe samples were delivered to the laboratories of Zimpro, Inc., located in nearby Rothschild, Wisconsin for weight sample determination. Coupon weights were determined using a Sartorius Model 3713 MP electronic balance.

Subsequent to the completion of the test, coupons were removed from the coupon holders by Utility personnel and placed in polyethylene bags which allowed the identification of each particular coupon. Only the excess moisture was blotted off with paper toweling. The samples were again delivered to Zimpro, Inc. where weight determination on the coupons samples was performed in a manner similar to that described previously above.

Dried Coupon Weight Determination as Performed by EPA

After having been weighed at Zimpro, Inc., the test coupons were shipped to the EPA Research Laboratories in Cincinnati, where the following procedures were undertaken in an effort to determine their dry weight. Coupons were stored in a 103°C oven. Prior to weighing they were removed from the oven to cool in a dessicator for approximately two hours. After the weighing was completed they were again returned to the oven. This procedure was repeated at intervals ranging from four to 15 days. In all, 12 sets of weight determinations were performed on these samples over a 97 day period.

Hardness Testing as Performed by U.S. EPA

Testing of the pipe coupons for hardness was performed at the EPA Laboratory in Cincinnati, Ohio. A description of the hardness testing

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procedure performed on the asbestos-cement pipe samples is contained in Appendix B of this report.

Sampling of Chemical Feed Solutions

A sample tap had been installed on the downstream side of the coupon holder for the purpose of obtaining and analyzing samples of the water to which the coupons were being subjected. In particular, it was desired to record the actual concentrations of zinc chloride and the pH condition of the water. However, during the course of the six month long test, only one such water sample was taken. This sample, taken on December 4, 1980, was analyzed by Zimpro, Inc. for pH and zinc concentration.

CEMENT-MORTAR LINING

Pipe Sampling

Pipe samples from all three test sections were obtained by saw cutting a six inch annular section from the pipe. From this six inch annular section smaller coupons were made by further saw cutting. The removed asbestos-cement pipe was replaced with a new section of asbestos-cement pipe, and repair sleeves were placed over the sampled section such that the pipe could again be pressurized.

Measurement of Sample Thickness

The pipe thickness measurements were made on pipe coupons by utility personnel using a venier caliper micrometer. The values of such measurements are accurate to the nearest 0.05 mm.

Measurement of Calcium Loss

Bakelite mounted pipe samples were analyzed by the EPA research facility in Cincinnati to determine the degree of calcium loss occurring along the interior pipe wall. All pipe samples were bakelite mounted by Zimpro, Inc. according to the following procedure: Pipe specimens were mounted in thermoset bakelite powder using a Buehler specimen mount press and 1¼ inch diameter by 2 inch mold assembly. Mounted specimens were then progressively wet ground to a final grit finish of 600. The grit sequence was 180, 240, 400, and 600. The specimen sample number, and previously measured thickness, were recorded on the back of mount.

The calcium loss experienced by the pipe was quantified using two parameters, the distance of calcium loss from the interior pipe wall and calcium to silicon ratio composition within the deteriorated zone of the sample. In assessing these parameters, the EPA used a scanning electron microscope (SEM) in conjunction with Energy Dispersive X-Ray Analysis (EDXA). The SEM micrographs reveal topographic features of the surface of the pipe interior. The EDXA spectra showed the relative changes in the chemical composition of the surface of the pipe. EDXA analysis does not allow quantitative concentrations to be determined for particular elements

which may be present on the sample surface. However, it does allow the relative quantities of elements present to be estimated.

Pipe sections which were analyzed by the EDXA method were prepared according to the method described by Clark, et al.(7). Pieces of each sample, approximately 12 mm x 6 mm were mounted on 24 mm x 5 mm copper boats using a conductive graphite adhesive. These samples were then carbon coated in a Denton vacuum evaporater. Samples for determining background counts were also prepared, using only a copper boat and graphite adhesive. Each sample was then placed in a JEOL 100 B transmission electron microscope (TEM) operated at an accelerating voltage of 40kV and a beam current of 55 to 60 microamps. Using the SEM mode in a magnification of 300X, the specimen was examined both longitudinally and laterally in a regularly spaced rectangular array with seven to 10 consecutive areas of the size of 0.1 mm squared being analyzed by the EDXA.

Relative Hardness Sampling

Three inch by three inch pipe samples were prepared by utility personnel according to the methods previously described in the Section entitled "Pipe Sampling" herein. These samples were then shipped to the EPA research facility in Cincinnati for determination of relative hardness by the Rockwell method, "L" scale. The laboratory procedures describing measurement of relative hardness are contained in Appendix B of this report.

Asbestos Fiber Counting

Water samples were collected by utility personnel in standard one liter polyethylene screw cap containers. Each container was rinsed at least once with water from the sample source prior to the actual sampling. The samples were refrigerated prior to shipment to Montgomery Laboratories, in Pasadena, California, in insulated styrofoam containers.

At Montgomery Laboratories the water samples were analyzed to determine the number of asbestos fibers in the water according to the method described by Anderson and Long (8). At the start of the procedure, aliquots of 100 to 250 ml of each sample were filtered by suction through a 0.1 micrometer pore size filters (Nucleopore) backed by a 0.45 micrometer pore size Millipore filter. A backing filter was used to insure uniformity of deposition of the particulate material on the filter surface. A quarter section of the filter was cut while wet, attached to a glass, dried, and coated with carbon in a vacuum evaporator. A small portion (approximately 2 square millimeters) of the carbon coated filter was cut out with a razor blade and placed on 200 mesh copper electron microscopy grid. A small drop of chloroform was applied by syringe to affix the filter to the copper grid. The filter was dissolved using a modified Jaffe Wick apparatus. After the filter was dissolved, the grid containing the particulates embedded in the carbon film was placed in a carbon specimen holder in the transmission electron microscope (TEM) operated at an accelerating voltage of 80kV and 70 micro amp beam current, and viewed at a magnification of 17,000 times. At least 15 grid openings from each of two grids was examined for each sample.

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Identification of asbestos fibers was made on the basis of morphology, crystal structure, and elemental composition.

Water Quality Parameters

Throughout the test a number of critical water quality parameters were analyzed. These parameters included: pH, total alkalinity (as $CaCO_3$), chloride, sulfate (as S), phosphate (as P), total phosporus, fluoride, nitrate (as N), potassium, calcium, magnesium, sodium, copper, zinc, iron, manganese, silicon, and temperature (°C). The measurement of temperature was made by the utility personnel using a standardized centigrade mercury thermometer on site at the time of sample collection. The measurement for pH was also made by utility personnel. A sample was collected by completely filling a one liter screw cap polyethylene container, which was then transported immediately to the Town's municipal center. This procedure is important since the pH of samples taken from closed systems (those not exposed to the atmosphere) can change significantly because of the tendency for the sample to seek equilibrium with the carbon dioxide fraction of the atmosphere. By filling the sample containers completely and capping them immediately this potential interference is lessened since contact with the atmosphere is minimized. The pH values were determined utilizing an Orion research micro processor Ionalyzer-901 following standard calibration procedures. All other water quality parameters listed above were determined by Zimpro, Inc. Water samples were collected in the above described manner by utility personnel and transported directly to Zimpro's Rothschild laboratory. All analyses performed by Zimpro, Inc. were done in accordance with the EPA analytical methods (11) with the following modifications:

Procedure	EPA Methods
Alkalinity	310.1(a)
Sol. Chloride	325.2(b)
SO_4-S	375.2
PO_4-P	365.1
Total P	365.4
Fluoride	340.2
NO_3-N	353.1(c)
K	258.1
Ca	215.1
Mg	242.1
Na	273.1
Cu	220.1
Zn	289.1
Fe	236.1
Mn	243.1
Si	FAAS(d)

(a) Alkalinity - Measurement of pH is a necessary step in the determination of alkalinity. The pH analysis for the parameter was determined by a method described by Schock (12).

(b) Chloride - Method incorporated dialysis to remove organic color interferences.

(c) Nitrate - Zinc included to reduce interference as described by Downs (13).

(d) Silicon - Direct Aspiration Flame Atomic Absorption Spectroscopy.

SYSTEM FLUSHING

Asbestos Fiber Sampling and Analysis

Water samples which were analyzed for asbestos fibers taken during the system flushing test were obtained in the following manner: At both sample points, which included 6102 and 6303 Kirk Street, a 50 foot rubber garden hose was attached to the outside hose bib. The hose bib valve was opened such that water was running continuously both prior to and after the sample was taken. A glass one-half gallon bottle was used to gather the water samples. The bottle was rinsed four times with water running from the hose each time before a sample was taken. The sample was then poured into a one liter polyethylene screw cap sample bottle which was also rinsed with water from the glass bottle. Storage, shipping, and subsequent testing of samples sent to Montgomery Laboratories in Pasadena, California, is as previously described.

SECTION 6

RESULTS AND DISCUSSION

ZINC PRECIPITATION TREATMENT

The goal of the zinc chloride precipitation experiment was to determine whether zinc might precipitate onto the individual pipe coupons and thereby form a protective layer between the asbestos pipe and the utility water. It was anticipated, when the test procedures were designed, that the amount of zinc precipitated would be equal to the difference in coupon weights before and after the tests. Coupon weights before and after the zinc precipitation tests are presented in Table 2. However, prior to discussing the significance of these coupon weight results, several aspects of the test procedure itself need to be addressed.

As was mentioned previously, adequate quality control was found to be lacking in the monitoring of both the rate of flow passing through each segment of the test header, and in the zinc chloride concentration dosage being fed into each of the test lines. The flow passing the coupons was only recorded on a cumulative basis over the entire 217 day test period. However, dividing the cumulative flow over the duration of the test period provides an estimate of the average flow rates in Lines D, E and F being 3.84, 3.73 and 3.74 gallons per minute, respectively. Although the test was designed such that zinc concentrations of 1.0 and 2.0 mg/l were to be maintained in Lines E and F respectively, only a single set of zinc concentration analyses were made during the entire test period. This sampling was performed two days after the test run was initiated. This single sampling indicated that Lines D, E and F had respective zinc concentrations of less than 0.01 mg/l, 0.87 mg/l and 2.28 mg/l. The pH values for Lines D, E and F were 7.61, 7.54 and 8.81, respectively. With only a single sampling, the accuracy of the above chemical concentration dosage is extremely questionable. In an effort to corroborate this data, operator records for the zinc solution make-up were analyzed. The operator began recording the dates on which he replenished the chemical feed solutions on January 22, 1981, which was approximately one-quarter through the duration of the test run. He continued recording this data through the conclusion of the test. From these records it has been determined that 4,750 and 9,500 grams of zinc had been added to Lines E and F, respectively, during this period of the test run. Assuming the flow was relatively constant throughout the entire test period, an estimate of the zinc concentration can be made by dividing the total recorded amount of zinc added by the proportional amount of flow for the period of record. Based on the above assumptions, it has been calculated that average zinc concentrations in Lines E and F were 1.4

TABLE 2. ZINC PRECIPITATION TEST COUPON WEIGHTS

	Line D		Line E		Line F	
	New	Existing	New	Existing	New	Existing
Initial Wgt.	96.994	94.302	88.817	97.833	93.631	77.460
Final "Wet" Wgt.	66.84	98.24	82.45	90.31	90.55	89.51
EPA "Dry" Wgt.						
After 5 days	57.232	79.784	71.117	72.924	78.130	72.487
11 days	57.051	79.443	70.838	72.667	77.787	72.206
18 days	57.009	79.370	70.765	72.603	77.691	72.133
24 days	56.743	79.309	70.597	72.572	77.625	72.080
39 days	56.931	79.244	70.657	72.501	77.570	72.069
59 days	56.957	79.259	70.657	72.563	77.575	72.107
67 days	56.817	79.020	70.515	72.324	77.404	71.864
76 days	56.733	78.906	70.421	72.225	77.306	71.750
82 days	56.797	79.013	70.470	72.312	77.351	71.854
87 days	56.776	78.988	70.457	72.310	77.339	71.833
93 days	56.674	78.820	70.348	77.161	77.216	71.680
97 days	56.713	78.884	70.379	72.215	77.244	71.727

Note: All weights in grams.

and 2.8 mg/l, respectively. Based upon the single grab sampling and the long-term average determinations, it might be concluded that while the accuracy of the zinc concentration is unreliable, at least the approximate desired test dosages were achieved.

The parameter of paramount importance for this test was that of coupon weight. It is unfortunate that the moisture factor associated with the coupon weight was not realized at the onset of the test. The implications of this factor relative to the test results were realized only after the test coupons were removed upon completion of the test run. Since the initial dry weights of the coupons were not obtained, quantitative conclusions regarding this test are impossible, and even qualitative conclusions are extremely limited.

Analysis of the data contained in Table 2 suggests that all pipe coupons tested lost weight over the duration of the test. Four of the six test coupons showed weight losses of between 16 and 20 percent of their initial test weight. The existing pipe coupon placed in Line F exhibited a smaller decrease in the pipe coupon weight of only 7.4 percent. One possible explanation for this smaller decrease in weight may be due to the smaller initial weight of this particular coupon relative to the others used in the test. This particular result brings up one aspect which deserves discussion and subsequent consideration on similar future tests. Possible mechanisms for coupon weight loss or gain might include: corrosion of the pipe coupon by the water, physical erosion of the coupon by the water, and the precipitation of various ions within the water on the coupon. All of these mechanisms are surface area dependent. Since the relationship between weight and surface area is a nonlinear one, it is quite important to use coupon samples with a minimum variation in surface areas, and consequently weights. Coupon preparation procedures outlined in a previous section of this report suggests that all coupons were prepared the same size, 3 inches by 1-3/4 inches. However, the initial sample weights suggest significant size differences between the existing pipe samples in lines D and F, since the 17 percent difference in weight between these two samples is too large to be attributed to different sample thicknesses. It might be suggested that future coupon samples be ground to exact dimensions to insure minimal interference from surface area differences.

Data contained in Table 2 relative to the EPA's attempt to determine the dry weight of each coupon sample suggests the extreme difficulty in accomplishing this. Even after 97 days of drying, coupon weights still were not reproducible within the allowable accuracy permitted by the weighing equipment. However, it is useful to point out that coupon weights were within one percent of their final "dry" weight after 5 days of drying. This difficulty in determining coupon weight, in conjunction with the possibility that factors other than zinc precipitation may be responsible for coupon weight differences, suggests that perhaps a different method for determining the amount of zinc precipitated onto the coupons should be investigated. Perhaps a portion of the coupon itself could be pulverized, dissolved, and

subsequently analyzed for zinc chemically. Alternatively, it might also be possible to analyze for zinc through X-ray technology.

This test also made use of the determination of relative coupon hardness as a measure of assessing the effectiveness of the zinc precipitation. The relative hardness of the pipe coupons is presented in Table 3. A high pipe hardness value indicates a harder pipe sample, while conversely a low value indicates a softer sample. All pipe coupons sampled for relative hardness had been subjected to the test run procedure. It would have been useful to have had two coupons tested for hardness prior to conducting the zinc precipitation test, to serve as a control. In any case, the new pipe sample coupons showed virtually the same degree of hardness regardless of the zinc dosage. Also, existing pipe coupons in Lines F and D, which received an approximate 2 mg/l zinc dosage and no zinc respectively, showed little difference in the degree of relative hardness. However, the existing pipe coupon placed in Line E, which had been subjected to an approximate dosage of 1 mg/l zinc, showed a marginal decrease in sample hardness. The lack of a definite trend from no zinc dosage to a high zinc dosage in both the new and existing pipe coupons suggest the zinc did not affect the coupon hardness. The single softer coupon sampling observed in the existing pipe coupon taken from Line E is likely to have been a randomly softer piece of pipe initially.

It is also significant to note that the system water to which the zinc chloride was being added had been previously treated with polyphosphates to sequester iron and manganese in the raw water supply. The success of the sequestering process depends upon chelating the iron and manganese in their ferrous and manganous (+ 2 valence) states. Since the zinc used in this experiment was also in this same valence state, it is quite possible that the zinc was also sequestered in the same manner as the iron and manganese.

TABLE 3. RELATIVE HARDNESS OF PIPE COUPONS RECEIVING ZINC TREATMENT

	New Pipe	Existing Pipe
Line D - No Zinc	79	7
Line E - 1 ppm Zinc	78	-6
Line F - 2 ppm Zinc	81	5

Determinations made by U. S. EPA using Rockwell Hardness L Scale Values (B Scale Readings)

This may explain the lack of positive results from this particular test, while zinc precipitation protection has been documented to be successful in other instances (10).

CEMENT-MORTAR LINING

Introduction

The results of the cement-mortar lining tests can be placed into three major areas for discussion. First, analyses conducted in conjunction with this portion of the study sought to reveal the physical condition of the asbestos-cement pipe itself, prior to and after cleaning. A second phase of the testing consisted of determining values for water quality parameters of system water recirculated through the asbestos-cement pipe, prior to an after lining. This portion of the test provided the opportunity for an analysis of how the product water, the pipe and lining may be interacting. Finally, the asbestos fiber concentration in the water carried by the asbestos-cement pipe was analyzed, prior to and after lining, in order to provide data of major concern, since the presence of asbestos in water may constitute a potential health hazard. In the subsequent discussion, each of these three aspects of this study is analyzed and discussed in detail.

Pipe Sampling Analysis

It was the observation of water utility crews that caused the discovery of the asbestos-cement watermain problem when they noted what appeared to be badly deteriorated watermain on Fox Street. This section of the discussion of results will focus on the analyses made on pipe samples taken from the asbestos-cement watermain located on Fox Street. The results of the test data from the analyses performed on samples obtained from this pipe are contained in Table 4.

A logical point of beginning for testing the extent of the pipe deterioration was to measure the pipe coupon sample thickness. The asbestos-cement watermain installed in Fox Street was a six inch, Class 200 pipe manufacturered by the Johns-Manville Corporation. The manufacturer's literature specifies a minimum wall thickness of 19.81 millimeters for this class of pipe. A sample of new asbestos-cement pipe revealed a sample wall thickness of 21.97 millimeters, which is within the manufacturer's thickness specifications. When reviewing the sample thicknesses of the deteriorated pipe, both prior to and after various cleaning methods, the sample thicknesses of all 15 coupons measured were still in excess of the manufacturer's minimum specified pipe thickness. However, this thickness measurement included a deteriorated pipe zone which has been quantified by the calcium loss distance. When subtracting this deteriorated zone from the wall thickness measurements, all 15 samples would have undeteriorated thicknesses less than the manufacturer's minimum standard. This raises a question regarding the structural integrity of the pipe. It is therefore recommended that samples of asbestos-cement pipe be tested for strength if cement-mortar relining is considered as a rehabilitation technique.

It is difficult to assess the effectiveness of the various pipe cleaning methods from measurements of sample thickness, since there appears to be an inherent variation in wall thickness along the length of even a single piece of asbestos-cement pipe, ranging up to two millimeters. In fact, the

TABLE 4. ANALYSIS OF PIPE SAMPLES TAKEN DURING CEMENT-MORTAR LINING EVALUATION

	Process Step*	Description	Sample Thickness (mm)	Calcium+ Loss (mm)	Mean Ca/Si	Relative** Hardness
BACKGROUND		New Pipe	21.97	0.0	0.83	72
TEST LINE A	A		21.20	2.1	0.57	-2
	C	1/3 pt. sample	21.39	2.2	0.80	-3
		2/3 pt. sample	20.77	2.5	0.60	16
	E	1/3 pt. sample	21.30	2.2	0.35	-11
		2/3 pt. sample	20.74	2.2	0.60	-32
TEST LINE B	A		21.02	6.5	0.73	-6
	C	1/3 pt. sample	21.34	2.2	0.64	-5
		2/3 pt. sample	21.79	2.2	0.40	-8
TEST LINE C	A		21.34	4.1	0.50	-24
	C	1/3 pt. sample	22.73	4.1	0.49	-20
		2/3 pt. sample	21.65	4.4	0.47	-13
	I	1/3 pt. sample	25.57	6.5	0.68	-15
		2/3 pt. sample	22.28	4.4	0.84	-12
	N	1/3 pt. sample	22.90	3.5	0.68	-13
		2/3 pt. sample	20.45	3.0	0.53	-12

* See description of process step in Equipment, Test Design and Operation section of the report.
\+ Distance measured from the interior pipe surface.
** Modified Rockwell "L" hardness scale - see Appendix B.

pipe sample taken at the one-third point of Process Step I in Test Line C shows an increased thickness of over four millimeters beyond the thickness measured prior to cleaning. However, it is apparent that neither of the cleaning methods utilized significantly reduced the samples wall thickness.

The measured parameters of calcium loss and mean calcium to silicon ratios presented in columns 3 and 4 of Table 4 was an attempt to analyze the effects of pipe cleaning methods utilizing more sophisticated and sensitive technologies. It might be expected that each successive clearing run might further decrease the calcium loss distance until it approached the zero value indicated for the new pipe. Similarly, the mean calcium to silicon ratio would be expected to increase with each successive cleaning pass, until it approached the value shown for new asbestos-cement pipe of 0.83. However, the actual values for calcium loss distances presented in Table 4 indicate that neither of the cleaning methods were completely effective in removing the entire deteriorated zone of the pipe. In addition, it appears that successive cleaning runs affected this calcium loss distance only slightly. The analysis of mean calcium to silicon ratios provided inconclusive results. While some sample values for this ratio approached that of the new pipe, subsequent analyses following further cleaning indicated a reduced value for this parameter. From these results it might be concluded that either the method of mean calcium to silicon ratio determination provides results that are not sensitive enough to be meaningful, or the pipe cleaning techniques utilized produced variable results along the length of the pipe.

The analysis of the pipe samples for relative hardness revealed that the deteriorated pipe is significantly softer than that of the new asbestos cement pipe. However, similar to the previous two parameters discussed, the relative hardness was not significantly increased by either of the cleaning methods employed. Since neither of the cleaning methods was able to remove all of the softened pipe zone, as indicated by the results of the calcium loss and mean calcium silicon ratios previously analyzed, it is uncertain whether the apparent softness is applicable to the entire pipe wall thickness or whether this softened zone exists only in the deteriorated portion of the pipe. In order to resolve this question it is recommended that on future tests hardness sampling be conducted throughout the entire wall thickness. This could be accomplished by successively grinding off thicknesses of the pipe interior and testing for hardness.

Optical microscopic examinations of the pipe samples were attempted. However, no apparent relationship between the distance value of calcium leached and these microscopic observations were discovered.

Finally, it should be mentioned that data for pipe samples taken after the cement-mortar lining process have not been analyzed for the parameters contained in Table 4. The samples not analyzed include Process Step L in Test Line A and Process Steps DD and II in Test Line C. Although these samples were taken, they were not analyzed due to time and budget constraints. It was felt that the value obtained from examination of these pipe coupons may be marginal, and that more might be learned from future test-

ing under conditions which would be more representative of an actual distribution system.

Water Quality Analysis

Analyzing the changes in water quality during the periods of recirculation throughout the various cement-mortar lining tests can be important in assessing the effectiveness of the process. A summary of the water quality data taken throughout the duration of the cement-mortar testing procedure is presented in Table 5. Three sets of water quality data have been presented in Table 5 for those process steps in which recirculation was conducted after line cleaning but prior to cement-mortar lining. These three sets of data samples were taken during process Step I on Line A, and during process Steps G and K on Line C. Replicate samples were analyzed for the water quality on Step G on Line C. The recirculation water used in each of these test line runs was obtained from a hydrant at the Mesker Street well on November 17, 1980, and the water quality analysis of the source water is also contained in Table 5. It will be useful to compare the changed water quality of the aforementioned three post recirculation samples relative to background water quality obtained from the same hydrant at the Mesker Street well.

The major water quality changes in each of these three samples are quite similar. In each case there is a noticeable increase in the pH, and in alkalinity and calcium concentrations. In addition, water quality parameters which are dependent upon pH and carbonate chemistry of the water have also shown significant changes from the initial values. These water quality parameters include magnesium, iron, and silicon. Sulfate concentrations are markedly reduced from their original values due to their precipitation by the additional calcium being released from the pipe. It should also be noted that water quality parameters which are not greatly affected by the pH and carbonate characteristics of the water remained relatively unchanged. These parameters include chloride, total phosphorus, phosphate, nitrate, sodium, and fluoride. The conclusion to be derived from these water quality analyses is that calcium carbonate, and to a lesser degree silicates, appear to be dissolving from the pipe wall. This is an indication that the source water used for the recirculation is corrosive in nature.

A second set of water quality data presented in Table 5 illustrates the changes occurring in the water quality following the cement-mortar lining process. The initial water used for the recirculating tests following cement-mortar lining was obtained from the Municipal Center well (private: not connected to distribution system). All recirculation tests which were performed following cement-mortar lining were done on Line C. Three sets of water quality data were taken following recirculation tests. These tests were performed on water samples taken during process Steps Y, BB, and HH. The recirculation periods increased with each successive test run. The water quality samples taken during process Steps Y, BB, and HH represent recirculation run periods of 6, 10, and 14 days, respectively. The results of the water quality analysis for each of these steps can be compared to one another, since the line was flushed and refilled following each of these three

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TABLE 5. WATER QUALITY OF SAMPLES ASSOCIATED TAKEN DURING CEMENT-MORTAR LINING EVALUATION

	BACKGROUND				LINE A	LINE C				
	Mesker Well+			Municipal Center Well**	Step I	Step G		Step K	Step Y	Step BB	Step HH
Parameter*	11/17/80++		10/26/81	10/6/81	12/2/80	11/25/80++		12/2/80	10/15/81	10/26/81	11/9/81
pH	6.83	6.86	7.0	6.0	8.95	8.5	8.54	7.9	11.1	11.0	11.0
Alkalinity (as $CaCO_3$)	43.8	43.3	51.7	18	73.2	61.7	58.0	48.0	350	294	238
Cl	18.5	17.7	27.7	10	19.8	18.6	17.0	17.1	10	10	14.7
SO_4 (as S)	3.50	3.58	7.3	6.7	0.5	0.5	0.5	0.5	7.3	7.3	7.3
PO_4 (as P)	1.59	1.61	.10	.10	1.21	1.44	1.46	1.28	.10	.10	.10
Total P	5.72	5.81	.20	.20	5.01	5.49	5.49	5.43	.20	.20	.20
NO_3 (as N)	1.6	1.6	1.04	1.56	1.66	1.59	1.50	1.56	.88	.89	.97
K	1.65	1.62	1.08	.82	1.17	1.14	1.12	1.04	3.48	6.48	3.92
Ca	10.1	10.2	12.1	4.44	25.1	16.9	16.9	17.1	122	118	93.6
Mg	4.32	4.27	4.79	2.68	2.02	2.00	2.00	0.61	.03	.02	.03
Na	14.5	14.2	26.0	2.68	14.3	14.5	14.5	14.2	6.45	4.19	30.5
Cu	.01	.01	.01	.11	.01	.01	.01	.01	.01	.01	.01
Zn	.04	.01	1.28	.07	.01	.01	.01	.01	.01	.11	.01
Fe	0.8	0.7	.58	.01	.58	.17	.18	.01	.01	.01	.02
Mn	.03	.04	.04	.02	.01	.02	.01	.01	.01	.01	.01
Si	6.4	6.3	6.6	6.2	4.8	4.5	4.2	3.5	3.5	4.5	7.3
Temp. (°C)	9	9	9	1	4	6	6	5	13	11	--

\+ Sample taked from hydrant at Mesker and Corrozolla

** Sample taken from tank truck

++ Replicate sample taken

* All values in mg/l except pH and temperature

recirculation test runs. The most significant water quality changes during each of these test runs are the substantial increases in the parameters of pH, alkalinity, and calcium concentrations. The magnesium concentration in each test run was shown to exhibit a significant decrease, which is attributed to its precipitation as magnesium hydroxide from solution caused by the high pH. Water quality parameters which are not significantly affected by pH and carbonate chemistry for the most part remained unchanged or experienced only a slight increase or decrease. These parameters included chloride, phosphate, total phosphorus, fluoride, potassium and nitrate. The effects on concentrations of metals, including copper, zinc, iron and manganese were slight, due primarily to small initial concentrations of these elements in the recirculation water.

Because of the extremely large increases in pH, alkalinity and calcium concentrations, discussion of these results and their consequences is warranted. The pH value following each recirculation test run in the cement-mortar lined pipe was approximately 11. This large increase in the pH value from the original value of 6 is due to the initial leaching of cement from the lining. Accompanying this pH change is an increase in both alkalinity and calcium concentration. It is significant to note that although all three values for both alkalinity and calcium concentrations are considerably elevated above that found initially in the recirculation water, there is a definite trend towards a decrease in these concentrations with each successive recirculation test. The water quality of the sample taken from Line C during Process Step Y, after being recirculated for six days, revealed alkalinity and calcium concentrations of 350 and 122 mg/l respectively. After the last test run in which the water was recirculated for 14 days, the water quality for these two parameters showed lower values of 238 mg/l and 94 mg/l for alkalinity and calcium concentrations respectively. The water quality values for these two parameters obtained from the sample drawn during Process Step BB (15-17) was between the values observed in Step Y and after the last test run, thereby suggesting a definite decreasing trend in these two parameters despite the fact that recirculation durations were increasing. These results are corroborated by the results of a six year leaching study conducted on cement lined pipe (9). This study measured the total dissolved solids (an approximate indicator of all cations and anions in a solution) of distilled water which was placed in a cement-mortar lined pipe and withdrawn every three or four days for analysis over a period of six years. The results of this study showed that from a peak value of 1200 mg/l total dissolved solids measured during the first three days of the test, the concentration of this parameter plummeted to less than 200 mg/l after the first month. After a period of approximately 10 months, the value of the dissolved solids had decreased to approximately 50 mg/l and remained relatively stable at this value for the duration of the test. Thus it might be anticipated that had this recirculation test been continued for a period of several weeks, the calcium, alkalinity, and pH values might be expected to be considerably lower than that indicated by the data in Table 5.

Should cement-mortar lining be decided upon as a remedial solution for halting the release of asbestos fibers into the water, consideration must be given to the impact that the increased pH and alkalinity may have on the

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product water. It should be noted that drinking water standards contain neither primary nor secondary limitations for pH or for concentrations of alkalinity and calcium. While the pH of most utility waters falls in the range from 6 to 8, there are a number of utilities in Wisconsin alone which have product waters with pH in the range of 9 to 10. It should also be remembered that a rehabilitated system would essentially pass water through a lined pipe only once, and would not be constantly recirculated. Thus, the actual pH from a relined distribution system should be expected to be lower than that reported in Table 5. With regard to alkalinity and calcium concentrations, it is not unusual to find utility waters in eastern and southeastern Wisconsin having similar calcium and alkalinity concentrations. The Safe Drinking Water Act identifies total residue of 500 mg/l as a secondary water quality standard. A secondary water quality limitation is one which does not present a hazard to health but may be objectionable for aesthetic or other reasons. The relationship between total residue and the water quality parameters of alkalinity and calcium is not a direct one, since total residue encompasses concentrations of all dissolved ions and non-dissolved particulates in the water. Should cement-mortar lining be chosen as a remedial method for eliminating asbestos from the water it is recommended that particularly close attention be paid to the effects high pH and alkalinity values might have on the solubility of metallic ions, since primary drinking water quality standards for these elements have been established. However, in most cases high pH and alkalinity will tend to precipitate these metals from solution.

Asbestos Concentration Analysis

The asbestos fiber concentrations found in water samples taken during the cement-mortar lining test procedure are contained in Table 6. Prior to drawing any conclusions from the data contained within this Table, discussion of the statistical significance of these data is essential. In accordance with the Interim Method for Asbestos in Water (8), asbestos fiber concentrations which have been calculated based upon the counting of less than five fibers within the recommended 20 grids are assumed to be not statistically significant. Values contained in Table 6 which were calculated using fiber counts below this five fiber threshold value are identified with an asterisk (*).

The reader will note that all but one of the amphibole concentrations sampled during the cement-mortar lining test were either not detected (no fibers counted) or were calculated based on counts of less than five fibers, and thus were not statistically significant. In fact, the only sample showing more than five amphibole asbestos fibers was that taken for the recirculation water source obtained from sample from the hydrant at the Mesker Street well, which indicated asbestos contamination of the test water. Based on these results, nothing can be concluded from this test relative to the concentration of amphibole asbestos fiber.

The Interim Method for Asbestos in Water (8) also suggests that at the value of one million fibers per liter (MFL), the actual asbestos fiber content may be considered accurate within a factor of 10. Keeping this fact in mind

TABLE 6. WATER SAMPLE ASBESTOS FIBER CONCENTRATIONS TAKEN TAKEN DURING CEMENT-MORTAR LINING EVALUATION

Line	Process Step	Asbestos Fibers Amphibole (MFL)**	Asbestos Fibers Chrysotile (MFL)**
A	H (Background)[2]	0.32	1.6
A	I	ND	8.4
C	G	ND	87.5
C	K	0.16*	10.9
C	R	0.37*	8.4
		ND	49.2
C	U (Background)+	ND	ND
		ND	1.71
C	X	ND	0.39*
		ND	2.1
C	Y	ND	ND
		ND	1.6
C	BB	ND	1.3
C	FF (Background)++	ND	0.13*
		ND	0.42*
C	HH	ND	0.44*
		ND	ND

+ Municipal well water sampled from the tank truck.

++ Mesker Street well hydrant sample.

** MFL - Million fibers per liter.

* Not statistically significant, less than 5 fibers counted.

Note: Two values are reported where replicate samples were analyzed.

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when reviewing the asbestos fiber concentrations for those process steps conducted after the actual cement-mortar lining (process steps subsequent to Step T on Line C), little can be said quantitatively regarding the value differences. Six of the nine analyses for chrysotile fibers taken after the cement-mortar lining process had fiber concentrations that were either not detectable or were below the level of statistical significance. The remaining three values showed a maximum concentration of 2.1 MFL. Because of the factor of 10 accuracy of fiber counts near 1 MFL, it can be concluded that there is no statistically significant difference among these three values. In addition, it should be noted that chrysotile asbestos fibers were detected in Process Step U on Line C which indicates that the tank truck water used to conduct the recirculation test had been contaminated with chrysotile asbestos fibers. The lack of any significantly high values for chrysotile asbestos fibers in the samples taken after cement-mortar lining would tend to indicate that this process may be effective in preventing the release of asbestos fibers from deteriorating pipe.

Focusing on the analysis of asbestos fiber concentrations prior to the cement-mortar lining, we are confronted with a considerably higher range of fiber concentrations. It should be noted at the outset that the water source used for flushing prior to and intermittentantly in the various process steps was contaminated with asbestos fibers reported to be on the order of 1.6 MFL. Referring to the fact that at concentrations near 1 MFL the actual concentration may be considered to be accurate within a factor of 10, it could be concluded that any values reported in Process Step I in Line A and Step G through R in Line C which have values less than 10 MFL may not be statistically different from the fiber concentration quality of the background water used for the test. Only two chrysotile fiber concentrations significantly greater than 10 MFL were identified. These included the asbestos fiber concentrations sampled during Process Steps G and R in Line C. Both of these samples had been taken after the lines had been scraped and flushed. Consequently, it would seem reasonable to anticipate some increase in the asbestos fiber levels. However, the quantitative value of these increased levels requires discussion.

The Interim Method for Asbestos in Water (8) addresses the subject of fiber concentration accuracy. This method suggests that the fiber distribution obtained from the electron microscope grids for each sample be tested statistically against an assumed distribution. It is suggested that the chi-square statistic be used to determine whether the fibers found in individual grid openings are randomly distributed among the openings. If the result of the chi-square statistic indicates randomness of fiber deposition on the microscope grids analyzed, upper and lower confidence intervals can be established utilizing the Student-T distribution. In order to utilize this method of statistical analysis it is necessary to have knowledge of the fiber count grid distribution, since this distribution is essential in establishing the size of the confidence intervals.

To illustrate this point, a statistical analysis was conducted on replicate samples taken for Process Step R in Line C. Replicate samples analyzed for this process step indicated chrysotile fiber concentrations of 49.2 MFL and

8.4 MFL. In the first sampling 120 fibers were distributed among six grids, and an analysis of the chi-square statistic indicated that this distribution was random. Subsequently, a confidence interval was calculated for this sample using the Student-T distribution which indicated with 95 per cent certainty that the actual fiber concentration was in the range of 43.1 MFL to 55.2 MFL. A similar analysis was attempted for the second sample. However, this time the results of the chi-square analysis failed to verify the grid fiber distribution to be random. When such results are obtained, the Interim Method for Asbestos in Water (8) recommends filtering another aliquot of the sample, and reanalyzing it. A likely explanation for the discrepancy between the two samples may be due to the fact that the second sample was not a valid analysis. Perhaps a sample preparation problem prevented a random distribution of fibers required for the analysis. The above demonstrates the need for careful sampling procedures and statistical verification of asbestos fiber counts. It is recommended that a requirement for such statistical analysis be required as a part of all such future fiber concentration analyses.

Certainly, the above discussion illustrates that the difficulty of analyzing and quantifying asbestos fiber concentrations is primarily responsible for the inability to make more definitive conclusions regarding the success of the cement-mortar lining in preventing the release of asbestos fibers from the asbestos-cement pipe. It may be useful to point to the success reported by Yuskus (14) in using a cement-mortar lining to prevent the release of a chlorinated organic contaminant, tetrachloroethylene (TCE), contained in a vinyl pipe lining installed on asbestos-cement pipe. TCE concentration reductions in the range of 96% to in excess of 99% were reported on test sections of watermain located in Waltham, Massachusetts. Since laboratory methods for the detection and measurement of organics by gas chromatography have been well established, the reliability of these data is substantial greater than that of the asbestos fiber concentrations. It should also be noted that TCE molecules are significantly smaller than asbestos fibers. Therefore, it would be quite logical to expect the cement-mortar lining to be considerably more effective physical barrier to asbestos fiber release.

SYSTEM FLUSHING

The results of the test for asbestos fiber concentrations in the water samples taken during the flushing test are presented in Table 7. Of the 14 water samples taken, six revealed no detectable asbestos fibers. These six samples have been identified with ND in Table 7. Four additional samples contained either one or two asbestos fibers on the 20 grid openings which were counted by the electron microscope. Although asbestos fiber concentrations are reported for these four samples, The Interim Method for Asbestos in Water (8) suggests that fiber counts of less than five are statistically nonsignificant. Thus it may be more appropriate to state simply that asbestos was detected in these four samples and that the fiber concentration values are near the minimum detection limit. The Interim Standards for Asbestos in Water also indicates that at calculated concentrations near 1 MFL, the actual fiber count can be assumed to be within a factor of 10. Based on this fact it would be risky to conclude that any value of asbestos

TABLE 7. WATER SAMPLE ASBESTOS FIBER CONCENTRATIONS TAKEN DURING AND AFTER FLUSHING TEST

		Asbestos Fibers	
	Process Step	Amphibole (MFL)+	Chrysotile (MFL)+
TEST No. 1	A	0.37*	0.18*
	C	ND	3.22
	D	ND	9.95
	E	ND	76.08
TEST No. 2	H	1.46*	ND
	I	ND	7.32
	K	ND	0.15*

\+ - Million fibers per liter.
ND = Not Detected
* Not statistically significant, less than 5 fibers counted.

fiber concentrations less than 10 MFL is significantly different from those values reported in the range of 1 MFL. Table 7 indicates three additional asbestos fiber concentrations below 10 MFL. After taking into account the reported test data in light of its statistical significance, only one test sample remains which exhibits a significant increase in the asbestos fiber concentration. This sample is the chrysotile concentration value reported in process Step E, which was the last sample obtained prior to the end of Test No. 1.

Although the reported values for chrysotile fibers contained in Table 7 may lead one to conclude that such fibers are increased during periods of high water velocity, a closer look at the statistical significance of these values mandates a more conservative conclusion, since only one statistically significant data point is available to support it. Therefore, it is recommended that the above conclusion be verified by additional research. On the other hand, the lack of any statistically significant concentrations of amphibole asbestos fibers suggests that such fibers are not released during high draw conditions.

It is also interesting to note that the sampling methods used may affect fiber concentration results. Millette et. al. (15) have reported fiber concentrations of approximately 10 billion fibers per liter obtained from a fire hydrant in Wisconsin after one full minute of flushing. However, fiber concentrations from two nearby household taps were only 5 and 7 million fibers per liter - a thousandfold difference.

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APPENDIX A

THE CENTRILINE LINING PROCESS

GENERAL

The Centriline Process consists of the mechanical cleaning and lining with cement-mortar of pipes in place. Linings are applied with centrifugal force from electrically driven equipment and can be of great advantage to both old pipes and new. Experience indicates that a cement-mortar lined pipe can be expected to have a life of 50 to 100 years. Approximately 10,000,000 feet of pipe have been lined by the Centriline Process in all parts of the world.

PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT-MORTAR LININGS

Cement mortar linings protect pipes both physically and chemically. Physical protection is provided by the lining forming a pipe within a pipe. The chemical protection, which is more important in a metallic pipe, is provided by the composition of the mortar. Should any aggressive fluid seep through the lining to the original pipe wall, it will have been rendered harmless from a corrosion aspect due to the free lime in the mortar which provides an alkaline condition.

Unlike bituminous or coal tar linings which depend upon bonding to the original pipe surface, a mortar lining is actually a structure conforming to a continuous arch and behaving as such. The arch itself is the main factor which keeps the lining in position and physical bond between cement-mortar and the original pipe surface plays a very minor role. Spawling is prevented by the arch action of the cement-mortar unlike other linings which depend upon a material bonding for its adhesion properties.

Although increased alkalinity of the pipe carried water can be expected following pipe lining, such lining is minimized in the case of Centriline linings by the incorporation of natural cement or suitable additives in the mix which stabilize the free lime in the Portland cement and inhibits its loss from the lining. A cause of cement leaving the pipe walls of spun concrete pipe and mixing with the water is attributable to the manner in which such pipe is constructed. The centrifugation of the pipe causes laitance and fines to rise to the internal surface of the pipe and under flow conditions free lime will again be imparted to the water for a period of time. A Centriline mortar on the other hand is very homogenious and tends to remain so in application.

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CLEANING

The cleaning of pipe lines is normally carried out prior to cement-mortar lining. A mechanical cleaner is normally of a flexible design which allows it to negotiate bends. A series of scraper blades and brushes is attached to the cleaner and both end are fastened to a steel cable which in turn attached to winches at either end of the pipe section to be cleaned. Cleaning is effected by means of winching the cleaners first in one direction and then the other and this is carried out until the pipe is satisfactorily cleaned. This operation can be done in dry conditions, but at times water is introduced in order to flush out the cleaning debris while the cleaning is in progress. After this phase of the operation has been completed, the section of main which has been scraped is flushed with water to remove the scrapings. After removal of any standing water, the pipe is ready for lining. In the case of pipe which has been previously lined with bitumen or other inert materials, it is important to remember that only loose material needs to be removed before application of the mortar lining. It is not necessary to chip out any materials which remains firmly attached to the pipe wall.

THE MORTAR

The cement used in the Centriline process is ordinary Portland cement complying with ASTM C.150 or British Standard 12. The mixed proportions vary from 1:1 to 1:1½ of cement and sand by volume. Individual conditions may dictate variations in the composition of the mortar, such as the use of sulfate resistant cement. The water to cement ratio varies from 0.35 in large diameter pipes to about 0.42 in smaller diameter pipes, since the mortar must be pumped. The sand should be a clean, hard, silica material uniformly graded from coarse to #150 (0.1 mm) sieve size. The grading will vary according to whether the sand is required for small pipe for which the mortar must be pumped or a larger diameter pipe. A finer sand will be needed for work in small pipe but by normal concrete sand standards, the grading for work in all sizes of pipe is usually finer than is commonly found on construction sites. The following is a typical sand gradation specification for the Centriline Process:

U.S. Standard Sieve Size	Size (mm)	Percentage Passing
14	1.25	100
20	0.85	70 -100
40	0.45	15 - 70
60	0.23	5 - 25
100	0.18	2 - 10

Some material should be incorporated in the mix to prevent excessive leaching of free lime, to retard the setting time, and to increase the plasticity of the mortar without increasing the water to cement ratio. These desirable conditions can be brought about by the addition of either of two materials, natural or pozzolanic cement, or a commercial concrete retarding

and densifing agent. The leaching out of free lime can be best prevented by production of a dense, impervious mortar. Natural or pozzolanic cements assist in two ways: they provide the additional fines required to raise the mortars density, and by reacting chemically with the Portland cement they tend to stabilize its free lime content. If the initial and final sets of the mortar can be delayed, the chance of drying and shrinking microfissures will be reduced. The use of natural or pozzolanic cement causes a slower strength increase in mortar. However, the small loss in compressive strength is rather insignificant when the primary purpose of the lining is not structural in nature. The use of cure accelerators should not be attempted since these would increase the possibility of shrinkage during drying. It is possible to return cement-mortar lined pipes to service after a 48 hours curing period. This time may be reduced to 24 hours under some circumstances if the line pressures are not excessive.

THE LINING OPERATION

The lining thickness required is governed by the diameter and condition of the pipe and by the type of fluid which the pipe is designated to carry. AWWA specifications for cement-mortar lining of water pipes in place (#C602-55) have made recommendations as to suitable lining thicknesses for various size pipes. These thicknesses are only a guide and can be modified depending upon conditions. The Centriline Process is capable of exceeding the full range of recommended cement-mortar lining thicknesses.

Since the lining machine travels at a constant speed and extrudes a constant quantity of mortar, the lining thickness is directly proportional to the machines lineal progress. Control of travel speed of the machine is determined by the rate at which the machine is winched through the pipe. The thickness of the lining can be checked from time to time by means of inserting a depth gauge into the freshly applied mortar. The velocity, kinetic energy and momentum of the mortar particles impinging on the pipe wall will vary with the diameter of the pipe to be lined and the size of the centrifugal lining machine. A characteristic of the Centriline Process is that the velocities are designed so as to eliminate any possibility of particle rebound. The mortar is pumped to the lining machine by means of a mortar pump capable of providing pressures up to 1,200 psi. Once lining operations commence, an average of approximately 800 feet of pipe can be lined per day.

CURING

The curing of cement-mortar lining should be accomplished by introducing fresh, clean water at pressure into the pipe such that it will create a moist atmosphere. Ideal condition can be created by bulk heading the end of the pipe using wet burlap bags, plastic covers or wood bulk heads. The cure can be obtained between 8 and 12 hours after the final set of mortar has taken place. The strength gain of a rich cement-mortar is rapid. An average Centriline mortar mix will have a compressive strength of 4,000 psi at three days, 5,000 psi at seven days, and over 7,000 psi at 28 days.

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Additional 28 day strengths are as follows: tensile strength 750 psi, flexural strength, 1,120 psi, dynamic modulus of elasticity 5.08 million psi.

Under emergency conditions the pipe line can be returned to service within 24 hours of lining provided that pressure within the pipe is kept to a minimum. However, 48 hours is considered a safer period to allow for initial curing without subjecting the mortar to the stresses of pressure and velocity. Chlorination and subsequent flushing can be performed as soon as curing is complete.

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APPENDIX B

PROCEDURES FOR HARDNESS TESTING

INTRODUCTION

Piping materials used in water distribution systems may be changed by the water being transported. One of the ways to measure structural changes is with tests of the material's hardness. Corrosion of asbestos-cement pipe causes the loss of certain elements in the pipe and this changes the structure of the pipe composition. Hardness tests measure the structural changes in the pipe.

SAMPLING

Samples of pipe are obtained from municipal water distribution systems. The sample pieces are cut from the pipe in 2 inch by 2 inch or larger sizes (up to 5 by 5 inches). An identifying code is written on the back of the sample and the sample is sealed in a plastic bag.

SAMPLE PREPARATION

Samples of pipe are cut to a size between 2 by 2 inches and 5 by 5 inches. Samples are shaken to remove loose material. Generally no other sample preparation is necessary.

SAMPLE ANALYSIS

In Rockwell testing the hardness number obtained represents the additional depth to which a ball is driven by a heavy load - beyond the depth of a previously applied light load. The minor load is applied first. Then the major load is removed and the hardness number is automatically indicated on the dial gauge.

Before each set of measurements a standard plate is measured and the instrument checked for reproducibility.

The Rockwell L test uses a $\frac{1}{4}$ inch ball penetrator, a 60 kilogram-force load and a plant anvil support. The analysis is as follows:

1. Place pipe piece on tester.
2. Rotate the lever wheel until contact is made.
3. Apply the minor load.
4. Rotate level wheel to set the dial gauge to zero.

5. Apply the major load by pushing the release bar.
6. Wait ten seconds* and read the hardness number on the B scale of the gauge.
7. Remove the applied loads and the sample.
8. Clean the penetration ball with a cloth.

*Corroded asbestos-cement pipe has a tendency to act like some hard rubbers and change slightly under sustained uniform pressure. As suggested in the Rockwell Test Manual, the load was applied for a period of time (10 seconds in this case) before the measurement was made, in order to improve reproducibility.

INSTRUMENTATION

Rockwell Hardness Tester Model 3JR, Number 3JR-6006, Wilson Mechanical Instrument Co., Inc. New York Property No. 634. Operation is described in the Wilson Hardness Tester manual RT.72.

The tester is calibrated yearly by Acco Industries, Inc.

SAFETY

The asbestos-cement pipe pieces are kept in sealed plastic bags except during the actual analysis. All dust is cleaned up with wet towels and disposed of in sealed plastic bags.

QUALITY CONTROL

Although the Rockwell L test has been standardized for some plastics it has not been standardized for asbestos-cement pipe. Before and after each set of measurements a standard soft metal plate is tested to insure that the instrument is maintaining the same parameters throughout the set of analyses. All measurements are currently done on a relative basis. The hardness readings from a piece of used pipe are compared to those from a piece of new pipe.

Reading from the standard soft metal plate have shown good reproducibility throughout the analyses carried out thus far.

STANDARD METAL PLATE READINGS

Test Block 67-003534

REPETITIONS	1	2	3	4	5
RUN 1	106.8	103.0	103.5	103.0	103.5
RUN 2	104.0	104.5	104.5	103.0	105.5
RUN 3	102.0	106.7	102.7	103.0	102.5

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DATA HANDLING

Each pipe sample is tested for hardness on five different areas of the sample. A mean and standard deviation are determined. Comparisons between hardnesses of different pieces of pipe are done using the Student t-Test.

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APPENDIX C

METRIC CONVERSION FACTORS

1 foot = 0.305 meters

1 inch = 0.0254 meters

1 inch = 2.54 centimeters

1 gallon per minute = .0631 liters per second

1 gallon = 3.785 liters

1 pound = .454 kilograms

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